THE PATHFINDER RAVEN SMALL UNMANNED AERIAL VEHICLE

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ABSTRACT

This paper provides an overview of the development of the Pathfinder Raven Small Unmanned Air Vehicle (SUAV) by the U.S. Army Natick Soldier Center and AeroVironment, Inc. The concept for this SUAV system was initially explored during the Military Operations in Urban Terrain (MOUT) Advanced Concept Technology Demonstration (ACTD) and brought to fruition during the Pathfinder ACTD. The spiral development process, the associated operational requirements and guiding principles used to quantify vehicle performance, physical characteristics, and methods of operation, are taken from the conceptual design stage to the current production aircraft. The Pathfinder Raven aircraft has undergone numerous design refinements and improvements in its evolution from concept to production. The current production Pathfinder Raven SUAV meets or exceeds the initial design objectives that could be boiled down to "do what a Pointer UAV does at half the size, cost, and weight." The production Pathfinder Raven SUAV is currently being used by U.S. Army and United States Special Operations Command (USSOCOM) forces in combat operations worldwide in the global war on terrorism.

1 INTRODUCTION

The SUAV capability was identified during the MOUT ACTD (FY98-02). This program focused on identifying technology solutions in 33 requirement areas for dismounted forces fighting in urban terrain. The Pointer SUAV, an AeroVironment, Inc. product, was provided as a technology solution for meeting the requirement for an organic intelligence gathering tool. Initial warfighter experimentation with the system provided positive feedback and identified some shortfalls which were addressed by the program before the culminating demonstration. These included addition of an infrared (IR) camera for night operations, shrinking the ground control unit to a man-portable size, integration of the military P(y)-code global positioning system (GPS) and receipt of approvals from the Army spectrum manager for military use.

Experimentation data and Soldier feedback gathered throughout the MOUT ACTD clearly demonstrated enhanced warfighter performance and resulted in user acceptance during experimentation. During the program's culminating demonstration in September of 2000, twenty-eight technologies satisfying a variety of requirements were utilized. The Pointer SUAV was ranked 3rd among those, validating the military utility of the SUAV capability.

Technology successes during the MOUT ACTD resulted in funding for an experimentation extension during the extended user evaluation period of the MOUT ACTD (FY01-02). During this period, limited funding allowed the team to pursue further development of technologies that had demonstrated military utility. The Pointer SUAV had been a clear success, but had also exhibited shortcomings which could not be addressed in time for MOUT ACTD's culminating event, chief among them its size and weight. The MOUT ACTD funded AeroVironment in April 2001 to explore the feasibility of a platform with the same capability at half the size and weight. The Flashlite SUAV resulted. A subsequent Phase II contract award yielded the first Raven SUAV.

The Pathfinder ACTD (FY02-06), while not a follow-on to the MOUT program per se, leveraged the MOUT ACTD team as it kicked off in 2002. The focus of the Pathfinder program was to develop a system to provide a real-time reconnaissance and surveillance capability for the small team or individual operator through the use of a wireless network of sensors. The Pathfinder ACTD funded further development work on the Raven in March of 2002 which resulted in what is known today as the Pathfinder Raven SUAV System.

2 THE PATHFINDER RAVEN SYSTEM

The Pathfinder Raven SUAV is primarily a reconnaissance, surveillance, and target acquisition system. The SUAV provides the small unit with enhanced situational awareness and increased force protection, by providing the means for expanded reconnaissance/surveillance, coverage of marginal maneuver areas, as well as increased target acquisition capability and an ability to reduce exposure in high-risk situations. The system has proven itself to be a critical asset, acting as a force multiplier in the conduct of intelligence, surveillance and reconnaissance operations from remote locations, reducing or eliminating enemy contact.

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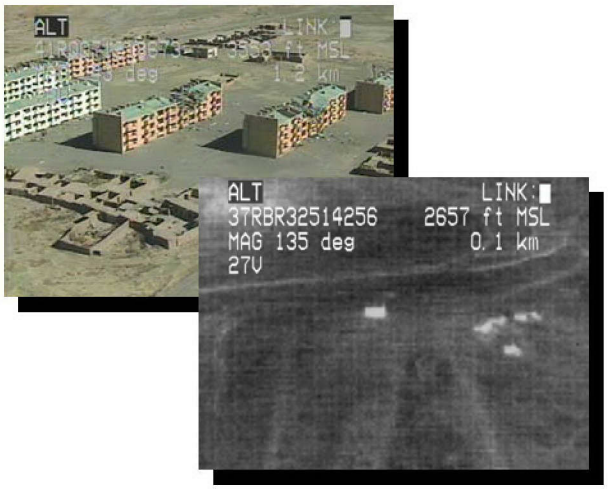

Figure 1 Day and Night Video Imagery

The Pathfinder Raven System is a man-portable, electric powered SUAV designed for operation with dismounted operators incorporating day (electro optical) or night (IR) imagers. Air vehicle weighs 4 lbs. with a wingspan of 4.5 ft, and is capable of 80-minute flights using rechargeable batteries or 100-minute flights with one-time use lithium batteries. The air vehicle is capable of a nominal operating range of 10 km under manual, semi-autonomous, or full autonomous operation, and incorporates military P(y)-code GPS for navigation. The Pathfinder Raven SUAV requires no special equipment during launch and recovery. The system is hand launched by a standing operator and recovered in a deep stall configuration allowing for operation in small complex terrains. The aircraft speed range is 20 to 70 mph.

3 SYSTEM DEVELOPMENT APPROACH

Spiral development is characterized by an iterative cycle of requirements definition (and re-definition), prototyping, systems architecture development, and user feedback. The development spiral is described in bulleted form and graphically in Figure 2.

- Concept is introduced to users.
- Users identify requirements for the system.
- Prototype is designed based on requirements.
- Users evaluate prototype (and requirements).
- New requirements or design guidelines are created.

As success is achieved in each design cycle, the scope of each successive design cycle is increased to get closer to the final product and to include a larger representation of the user group(s).

A basic premise of the development cycle is recognizing that the user may not be able to articulate clearly a particular requirement. Most often the user is better at looking at an existing prototype and saying "these things I like," and "these things I don't like." During the development of the Pathfinder Raven SUAV, the Pointer SUAV provided an initial reference point for both development and user feedback. Using this method, significant progress toward a user accepted product using relatively low cost prototypes.

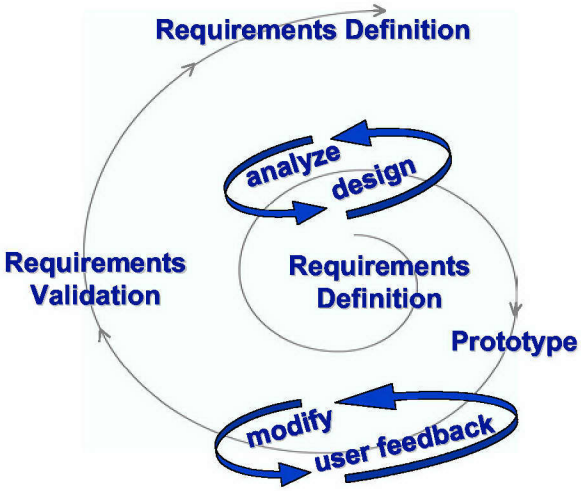

Figure 2 Development Spiral

4 REQUIREMENTS DEVELOPMENT

Requirements for this system were gathered formally and informally throughout the spiral development process. Contributors to this process included users, trainers (Pointer and Raven SUAV) and members of the engineering team. Significant focus was put on the user input to the system. Extensive data collection during the MOUT ACTD rendered both quantitative and qualitative data which was used to generate the Pathfinder Raven concept and initial prototyping. Gathering user feedback continued to be a primary focus during subsequent spirals, as the system continued to be refined.

In 2002, the Pathfinder Team was tapped to support a United States Special Operations Command (USSOCOM) combat mission needs procurement of Pointer SUAV systems. The team developed a training cadre and program of instruction for the SUAV system during this effort. This provided two invaluable opportunities for the development team as it pursued the Pathfinder Raven. First, the members of the training cadre became expert users of the system, developing tactics and defining/refining the processes for its use in theater along with the students in their classes. Their extensive experience identified numerous more subtle system requirements which would not be obvious to the

occasional user of the system. Many of these related to the user interface. Secondly, the Pointer training events gave the training and development team an opportunity to regularly interact with users of the system. As these students received systems and deployed to fight the Global War on Terrorism, the training cadre became a focus for questions and trouble-shooting regarding the use and employment of the system. This feedback was invaluable in refining the user requirements for the Pathfinder Raven system.

Figure 3 Pointer Training Session

Early in the conceptual design phase, a list of operational needs and requirements was developed for the SUAV system to be used as guidelines throughout development. These guidelines, or requirements, were defined in collaboration with experienced warfighters from varying military backgrounds and service associations. These requirements were used as guidelines for performance and cost tradeoffs over the course of the development.

1. The SUAV system shall be for dismounted infantry forces. The operator is a highly trained infantry soldier, but not a pilot or a mechanic. The user interface must be simple, the system setup self-explanatory, and require only one or two persons to operate and carry.

2. The SUAV system shall be half the size and weight of the Pointer System. This criterion was heard repeatedly. The existing Pointer aircraft, ground control unit (GCU), and batteries required two people to transport and could not be carried in addition to normal field supplies. A smaller system also has less visual impact, and therefore is more difficult for the enemy to detect during operation. Trade-offs between system size and other requirement areas such as system capability, occurred throughout.

3. The SUAV system shall be based on technology available at the time of development (or in a maximum of 6 months). Pathfinder Raven was a quick-development program, and could not wait for long-lead items or technologies. Commercial off-the-shelf (COTS) parts were used wherever possible, and the elimination of custom pieces whenever possible reduced cost and simplified the manufacturing process.

4. The SUAV system shall be simple, reliable, robust, and effective. Simple assembly and operation was imperative. The user interface was designed with minimal controls, intuitive operation, and the ability to satisfy a large majority of its envisioned missions. The difficult combat environment was a constant consideration as well.

5. The SUAV system shall minimize cost. The simplicity of the system should be a factor that drives cost down, as well as the use of COTS parts. Time-saving fabrication techniques that differ from traditional Pointer methodology were employed whenever possible.

6. The SUAV system shall have performance equal to or better than Pointer including: link range of 10 km, flight speed of 27 - 50 mph, minimum flight duration of 1 hour, daylight color and thermal payloads, total equipment weight required for 20 flights of maximum 60 lbs, and launching (from a stationary position desired) and landing without special equipment, terrain (i.e. a runway) or environmental conditions.

These six requirements were the core of the system requirements and were referred to throughout the design process. During each spiral, additional detailed requirements were tackled. As the system evolved and more experience was gained in the operation and tactical use of systems like these, a more comprehensive set of requirements evolved, some of which were outside of the scope of this development effort. The Rucksack Packable Unmanned Aerial Vehicle (RPUAV) ORD (2004) adopted by United States Special Operations Command and the U.S. Army reflects some of these objective requirements.

5 PROOF OF CONCEPT: THE FLASHLITE SUAV

Several conceptual designs of the SUAV system and sub-components were developed and evaluated either in simulation or as prototypes at the outset of the initial design spiral. These included wingeron, aileron and Pointer-like concepts.

The wingeron concept proved to have stability problems and was not able to autoland as Pointer did. The aileron concept was more viable, but packaging was not going to be acceptable. The overall configuration that was finally selected was similar to the MOUT Pointer UAV at the gross level, but significantly different in the details.

Figure 4 Aileron Development Concept

A preliminary analysis of current and near term payloads, propulsion systems, and energy storage suggested that an airplane roughly half the size of Pointer could be produced, while maintaining Pointer performance. A radio-controlled model named Flashlite was fabricated and is shown in Figure 5. The size and weight was half that of Pointer, including allowances for the avionics, payload, and battery weight. The Flashlite verified the feasibility of the concept but was not optimized for maximum performance. This prototype also introduced improvements over the Pointer UAV with a snap-on wing design, spine-mounted motor and internal components, and a low-flying horizontal stabilizer. User feedback indicated that the Flashlite was right on the mark as far as size, weight, and performance, and that design improvements over Pointer were heading in the right direction.

Figure 5 Flashlite SUAV — Proof of Concept Platform

6 PROTOTYPE DESIGN AND ANALYSIS

The Flashlite demonstrated that it was possible to achieve Pointer performance at half the size and weight. This launched further development of the system under the Pathfinder ACTD. The air vehicle was renamed Raven after the Norse God Odin's use of ravens for reconnaissance. A subsequent renaming occurred later to the Pathfinder Raven.

A design optimization effort began the next design spiral. Analysis was used to determine what could be expected from an optimized design. This optimization effort (*e.g.*, Grasmeyer 2001, Grasmeyer and Keennon, 2001) was employed to predict performance. Figure 6 shows a top-level overview of the optimization code architecture. The optimization code took a mission objective and packaging constraints as input, and produced an optimized design satisfying the requirements. The code consists of several mathematical models for all of the SUAV subsystems. Each of the subsystem models is built upon manufacturer data, bench test data, and flight test data (Figure 7). Figure 8 and Figure 9 show some sample plots derived from the battery and motor databases.

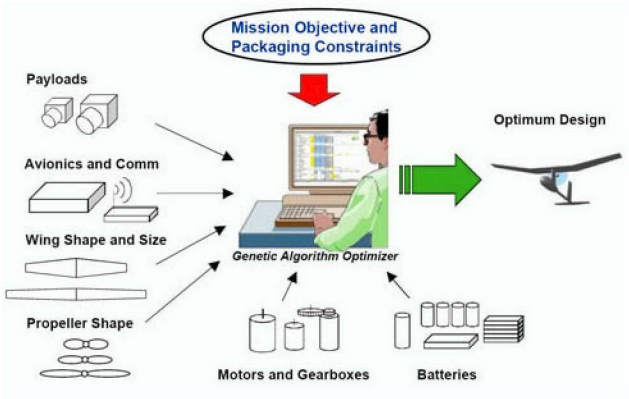

Figure 6 Optimization Code Organization

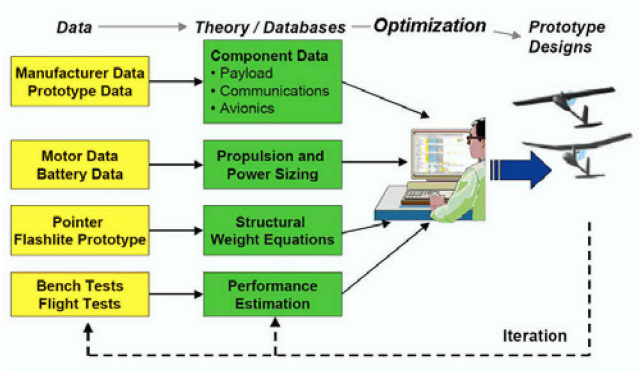

Figure 7 Experimental Data, Theory, and Component Databases Used for Optimization

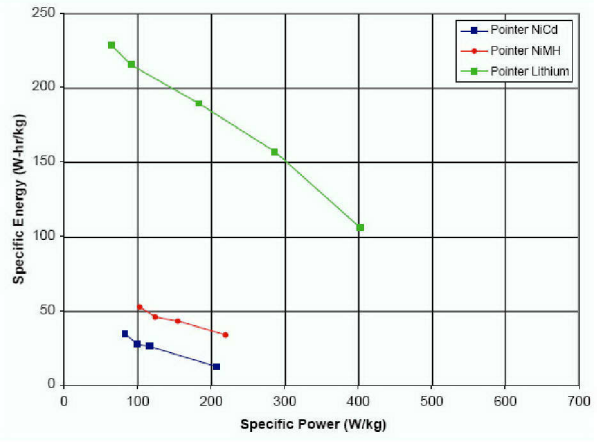

Figure 8 Ragone Plot of the Pointer Battery from Battery Database

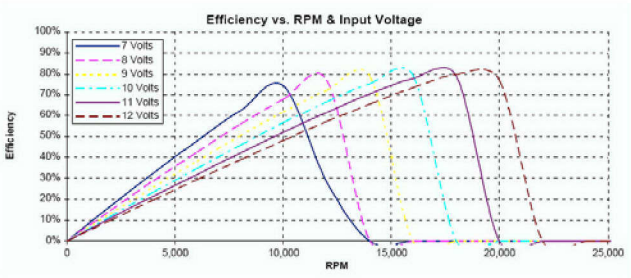

Figure 9 Sample Plot of Modeled Motor Efficiency

The result of this optimization effort indicated that a vehicle design with a gross weight of 3.5 lbs and wingspan of 51 inches would yield an endurance of 90 minutes, a speed range of 24 – 50 mph and carry payloads up to 0.26 lbs. The ensuing design targeted these parameters, which included a more aggressive goal for battery endurance. The main legacy of the optimization was that this analysis raised the bar for the endurance requirement of the vehicle from 60 to 90 minutes.

A Pathfinder Raven prototype (Figure 10) further validated the optimization code, models, and the performance of a vehicle that was closer to the optimum design. This prototype was fully functional, but was not widely demonstrated due to its prototypical nature. This airframe was hand-built and not mass producible. It was demonstrated to key users to obtain feedback on the system.

This air vehicle met all the key requirements, most importantly size and weight, that had been identified early and throughout the development process. It used a Pointer GCU as a controller. The airframe did have some key differences to the Pointer:

- The air vehicle required one battery (instead of two).
- The wings were attached to the body with nylon fasteners instead of rubber bands .
- A different tail configuration.
- Four channel operation (instead of one).

Figure 10 First Raven SUAV Prototype

7 LOW RATE INITIAL PRODUCTION

The Low Rate Initial Production (LRIP) yielded an updated airframe configuration. The first Block I Pathfinder Ravens were fabricated and delivered to the Pathfinder program office in May of 2003. These units used rapid prototyping techniques to the fullest extent possible in a very limited production run. Along with new body styling, the Block I Ravens demonstrated the ability to swap-out a modular payload nose. Payload options included a front/side look color camera, a front look IR camera, or a side look IR camera.

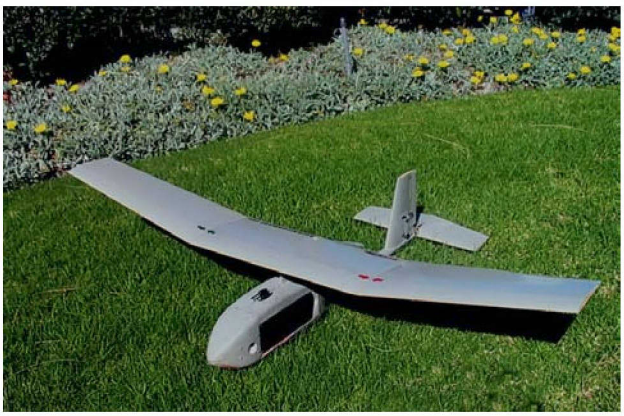

Figure 11 Block I Pathfinder Raven

The SUAV satisfied all of the requirements laid out by the user group, however numerous quirks were identified that impacted its ease of use.

The Block I Ravens were significantly more difficult to launch than the Pointer UAV. The Pointer, a 9 pound platform, required a running start for a hand-launch. The requirement for the Raven was that it be hand-launchable from a standing position. The Block I Ravens required not only a short run for launching, but also a significant

amount of skill in controlling the launch from the GCU. The addition of an air speed sensor was a key factor to improving the launch.

A second major problem was stability. Analysis indicated that this mainly due to the hand-build nature of the aircraft . Air speed feedback also improved the pitch stability of the SUAV.

Despite some of the shortcomings exhibited by the early Raven platforms, user acceptance was very high. The U.S. Army Program Manager-Unmanned Aerial Vehicle Small (PM-UAVS) witnessed early demonstrations. An Urgent Need Statement for Raven SUAVs resulted along with orders for Block II Raven Systems. Upon delivery, these systems were to be sent immediately into theater. It was critical that the Block II deliverables be as robust and refined as possible.

Block II Pathfinder Raven delivery occurred in late September 2003. The intervening months were consumed with refining the design and eliminating the shortfalls of the Block I system. The use of production-quality tooling provided a significant enhancement to the quality of the aircraft, as well as reducing the overall weight by more than 10%. The user interface on the GCU (software) continued to be refined. Throughout this process, the Pathfinder ACTD Technical Team and SUAV Training Cadre worked very closely with AeroVironment to assure that Block II would be ready for Soldiers.

Figure 12 Block II Pathfinder Raven SUAV (Current Production Model)

In early October, the training cadre deployed to Afghanistan with the Block II Pathfinder Ravens and conducted the first Raven training session. Employment of the SUAV in theater exposed weaknesses, most notably in the tail control surface servos, the motor, and the IR camera shutter. As each of these weaknesses surfaced, they were appropriately investigated and fixed.

The system continued to show great promise and the US Army exercised a buying option to increase their total buy to 179 3-bird systems. Concurrently, USSOCOM issued a Combat Mission Needs Statement for 59 systems. The system is now in full-rate production.

As with any R&D effort, there were numerous technical challenges associated with development. Overcoming the technical challenges is routine for companies in the business of R&D. However, in the case of Raven, the final and most daunting challenge was in bringing this system into full-scale production. The Pathfinder Raven SUAV is the first militarily useful man-portable SUAV to be produced in large quantities. Over the last year, AeroVironment has drastically expanded their production capability and successfully grown from a small R&D firm to a full-scale production house.

8 OPERATIONAL USE

The Pathfinder Raven SUAV is currently deployed worldwide in support of the Global War on Terrorism. SUAV systems are being used to great advantage for a variety of missions including route reconnaissance, battle damage assessment, direct action, force protection, convoy protection, detection of hand-emplaced obstacles, surveillance, special reconnaissance and dismounted patrol.

The Pathfinder ACTD continues to receive feedback from these users. These comments are overwhelmingly positive. Lessons learned are captured and fed into the Training Program of Instruction, to the manufacturer and the R&D community.

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- The Pathfinder ACTD SUAV Training Cadre.
- The Pathfinder ACTD and AeroVironment Engineering Teams.

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CONCLUSION

The success of the Pathfinder Raven system is attributed to a number of factors. Most importantly, this system was developed by users, with the government engineering team acting as a conduit to the developer/ manufacturer. The system would not be the success that it is without the input of the warfighter.